Magnetic-Damping Test of Convective Flows in Microgravity

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The fundamental objectives of this experiment are: (1) to test experimentally the validity of modeling predictions applicable to convective-flow magnetic damping in conductive melts as this applies to the directional solidification of metallic and semiconductor materials in the reduced-gravity levels available in low-Earth orbit; and (2) to assess the effectiveness of magnetic fields in reducing the fluid-flow occurrence in these materials during the space processing that results from density gradients (driven by either the residual steady-state acceleration or *g*-jitter) or surface-tension gradients (Marangoni flow).

During the past year, work has included Bridgman and floating-zone growth experiments, as well as numerical modeling of the Bridgman experiments. Ingots of gallium-doped germanium, germanium-silicon alloys (5-percent silicon), and indium antimonide-gallium antimonide (20-percent indium-antimonide) have been grown by the Bridgman method, while the floating-zone experiments were done with silicon samples.

For the gallium-doped germanium experiments (summarized in fig. 9, which shows data for the composition along the growth axes for four samples grown at different magnetic fields), convection is sufficiently vigorous to completely mix the melt at zero field. In the three nonzero fields, the data show that convection is reduced to the point that the compositions follow a diffusion-controlled curve for at least the first 30 percent of the length of the sample. At 5 Tesla, statistics show diffusion control over nearly the complete sample. These results confirmed the modeling prediction that an approximately 3-Tesla magnetic field would be required to achieve diffusion-controlled growth in the configuration that was used. The germanium-silicon alloy experiments showed that this alloy system is not gravitationally stable against convection as expected from a simple hard-sphere model of the melt, but that application of a magnetic field to the melt stabilizes it sufficiently to achieve diffusion-controlled growth. This is in contrast to indium antimonide-gallium antimonide, which exhibited complete mixing in the melt, even at a 5-Tesla applied magnetic field.

The silicon float-zone experiments were carried out in collaboration with the Kristallographisches Institut of the University at Freiburg, Germany, under a collaborative agreement with NASA. Using a mono-ellipsoid mirror furnace installed in a magnet in the MSFC Space Sciences Laboratory, 19 samples were grown and are being jointly analyzed by both university and MSFC researchers. These experiments extended to 3 Tesla the earlier experiments carried out at the university in their 0.5-Tesla magnet. By comparing these results with sounding rocket experiments carried out by the Kristallographisches Institut, the similarities and differences between reducing convection with an applied magnetic field versus reduced gravity have been elucidated. For samples grown in high-magnetic fields, both the Bridgman and floating-zone experiments provided some unexpected results. The magnetic field should reduce convection, and it does initially. However, findings from both types of experiments indicate that the effect of convective flow in the melt increases at some point during the growth (as is evident in fig. 9 for the gallium-doped germanium samples grown at 2.5 and 3.9 Tesla). One possible explanation for this is called “thermoelectromagnetic convection,” which is driven by currents induced by variations in thermoelectric properties along the solidification interface, and known to exist under such conditions as in the liquid-metal cooling systems of nuclear reactors. Although such currents will exist without a magnetic field, they would not cause any motion of the melt unless there is a magnetic field present. Whether thermoelectromagnetic convection is significant or not is an important question that will be addressed in the coming year, because it will have a substantial impact on the design of a magnetically damped flight furnace now under consideration as a future module for the Space Station Furnace Facility.

The near-future plans in the modeling area include investigating the sensitivity of systems experiencing solutal forces to gravity parallel to the growth surface, continuing work on the modeling of magnetic and microgravity effects on thermosolutal convection, and simulating magnetic experiments of gallium-germanium and germanium-silicon now in progress.

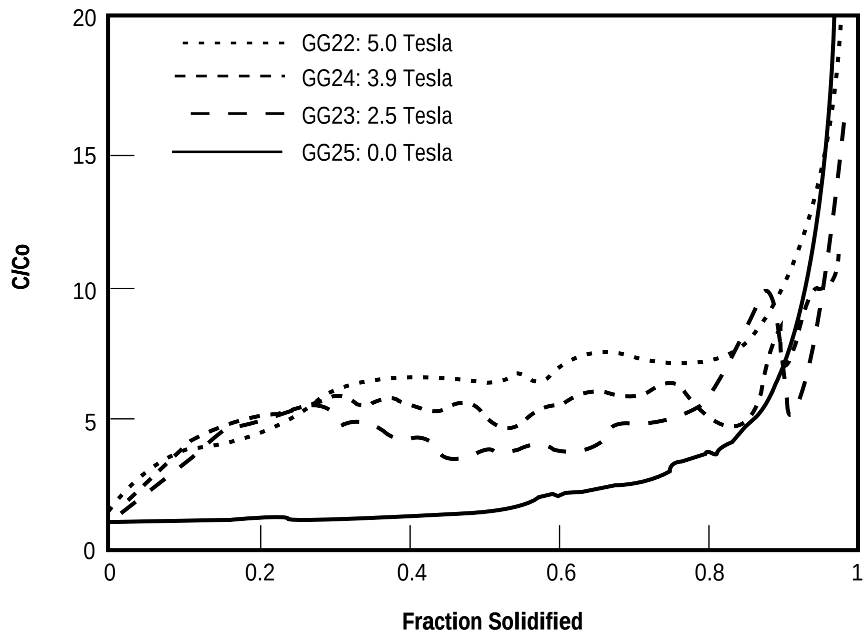

FIGURE 9.—Axial gallium concentration profiles versus field strength for Bridgman-grown germanium.

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